NEXT-GENERATION MATERIALS FOR CMP RETAINING RINGS

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ABSTRACT

Developments in Chemical Mechanical Planarization (CMP) systems and technology have enabled the advancement in semiconductor micro-processors by helping move towards smaller devices that require extremely tight process control, tight tolerances, higher quality of surface topography and planarity. A critical component of these CMP systems continues to be the retaining ring. The function of the retaining ring is to contain and position the wafer as it is being planarized. With proper material selection and design these rings can offer low polishing rates, uniform surface finish with a tight flatness tolerance and absence of large-scale topography in addition to high material stability with low vibration characteristics. All of these performance characteristics are related to the polymer materials' intrinsic surface properties and have a direct correlation to the wear resistance of the finished retaining ring.

Based on a prescreening of over 30 polymer compounds, a study was undertaken by Greene, Tweed & Co.'s Semiconductor Product Engineering Group that compared two (2) of the most commonly used materials for CMP retaining rings to three (3) Arlon® PEEK (polyetheretherketone) based compounds. All five (5) materials and compounds were characterized by coefficient of friction, mean square error (vibration), and weight loss using a Center for Tribology, Inc. (CETR) polishing Micro-Tribometer model PMT.

INTRODUCTION

CMP retaining rings made from basic shapes must be machined to tight tolerances. When in operation (Figure 1 retaining ring CMP head system) retaining rings must be compatible with other system components such as pads and slurries, and must not generate substances or particles that may be detrimental to the wafer fabrication process. Some of the more aggressive processes, such as oxide, require that these retaining rings be replaced as often as every 2 days. Considering that CMP systems can utilize up to 4 retaining rings per system, the replacement cost for a complete set of rings can be almost $5,000. Other significant costs in addition to unit costs are related to the labor of replacing the rings, the re-qualifying for process (uniformity of rate and checks for foreign material), and overall downtime of production. Depending on the individual process and applicable downtime, the true costs of replacing a set of CMP retaining rings can be many times the cost of the retaining rings themselves.

Figure 1: Representation of a Polishing Head System

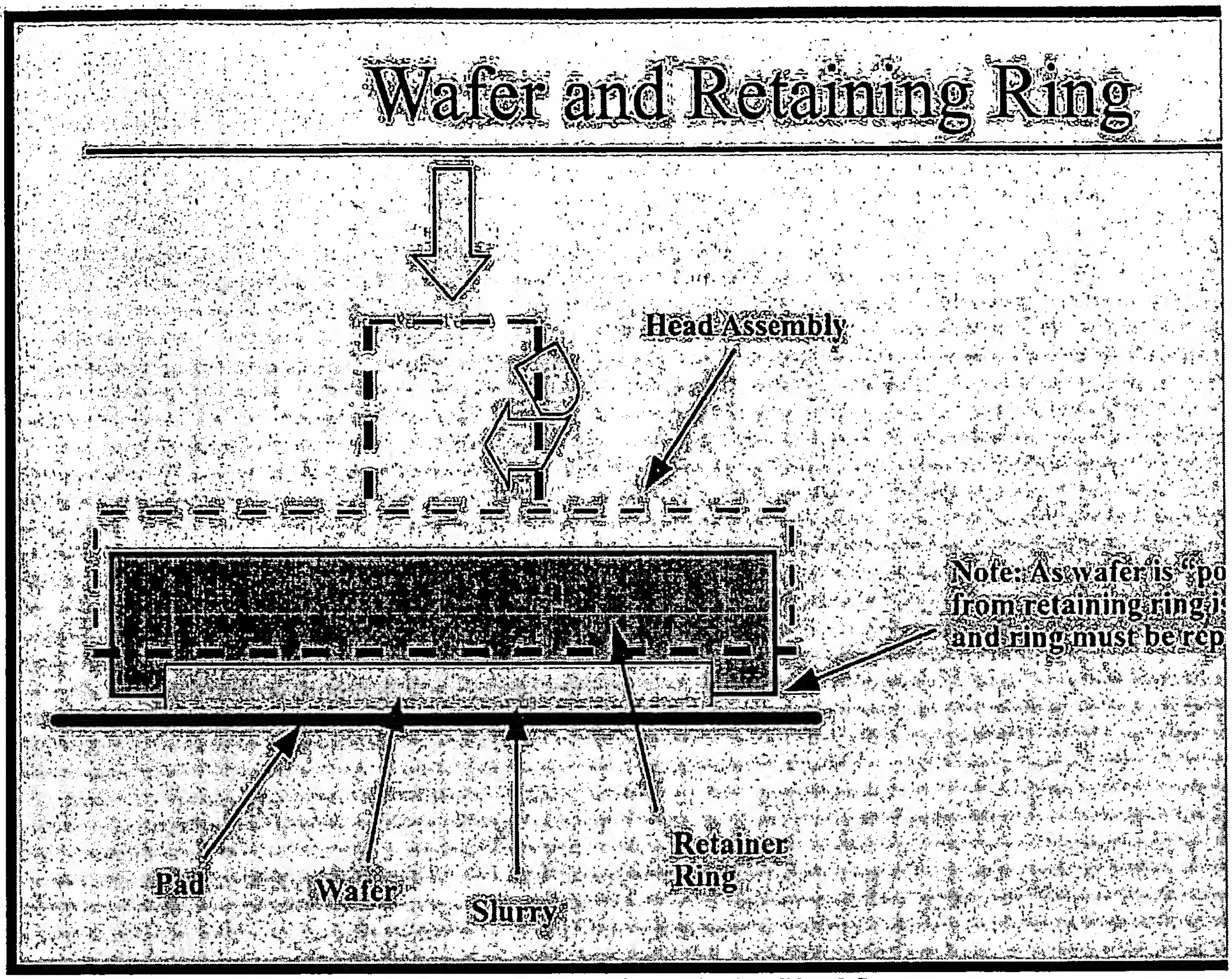

Figure 1: Representation of a Polishing Head System

A common goal of chip processors and original equipment manufacturers (OEMs) is to extend the service life of the retaining rings as much as possible without decreasing the service life of other key related components. Also, advancements in the design of other critical CMP equipment components such as the head unit add to the importance of finding better, longer-wearing rings to match the performance of these new components. Greene, Tweed & Co. Arlon® PEEK CMP materials offer the service life required by new designs and processes where the most commonly used materials under-perform as the results suggest in this study.

EXPERIMENTAL PROCEDURE

Polymer Materials

The most commonly used materials for CMP retaining rings are unfilled PPS (polyphenylene sulfide) and unfilled PC (polycarbonate which encapsulates a stainless steel ring). The (3) Arlon compounds used for comparison include carbon fiber reinforced (CFR) Arlon, Arlon 1330 and Arlon EX-2618. The (CFR) Arlon, Arlon 1330 and EX-2618 compounds utilize proprietary filler systems required for the intrinsic characteristics of CMP applications. Greene, Tweed & Co.'s Arlon grade materials are all based on Victrex's® Polyetheretherketone (PEEK) resin.

Sample Preparation

Material samples for the CFR Arlon , Arlon 1330, and Arlon EX-2618 were die cut from injection molded plaques.
Both the PPS and PC material samples were machined from extruded rod stock shapes.

All sample dimensions were die cut material to coupons with 0.75" (OD) outside diameter and 0.125" thick.

Testing Apparatus

A CETR polishing Micro-Tribometer model PMT was used to characterize the retaining ring materials in a series of tests. The model used is a stand-alone bench top CMP tester that provides the user with a fully instrumented CMP process on up to 2" wafer coupons and 6" pads. The CMP tester is capable of providing precision translational, rotational, or reciprocating motions to the friction pair specimens with speeds ranging from 1 RPM to 1000 RPM for rotational control, and from 1μm/sec to 15 mm/sec for translational control. A normal load is applied by a close loop servo - mechanism in the instruments' upper stage. The normal load can be kept constant or linearly increasing ranging from 0.5 mN to 500 N. In situ polishing pressures and relative velocities are achieved for the CMP process, that allow for development, incoming inspection and ongoing durability testing of the slurries and retaining rings as well as CMP process development.

Friction Force (F_x), normal load (F_z) and acoustic emission (AE) can all be measured and recorded at a total sampling rate of 20 kHz. Mean Square Error (MSE) can be monitored and recorded to correlate the stability and vibration characteristics in situ. All these parameters in addition to the calculated coefficient of friction are recorded and displayed in real time during the test.

Consumables

The polishing pad used was a Rodel IC 1010 polyurethane pad. The slurry was a Semi-Sperse® SSW2000 from Cabot Microelectronics. It had a 2-3 % concentration of H_2O_2 by volume.

Procedure

- The polishing pad coupon was attached to the bottom stage with a rotational speed set to 113 r.p.m. The polyurethane pad coupon was replaced with a new coupon for each polymer sample.
- The retaining ring coupon sample (0.75 in OD X 0.125 in thick disk) was attached to the upper stage of the sample holder with a double - sided scotch tape.
- Testing parameters for each material were consistent with an oscillatory motion of 5mm/s, a stroke length of 1 in, and a rotational speed of 113 rpm. A constant downward force (normal load) of 20 N was applied and maintained using a closed-loop feedback mechanism to keep the specified 10psi pressure. The test duration was 30 minutes at ambient room temperature of 22°C with a constant slurry flow.
- Data for each parameter tested was collected for each material at 0 to 2 minutes interval, at 15 to 17 minutes interval, and at 28 to 30 minutes interval. The average of two data points at each interval is used to present a comparison of the data.
- Data presented in this study for the MSE and weight loss is for the longest duration at 28 to 30 minutes interval.
- Two test samples per material were tested for repeatability under the same conditions.
- Monitored data during the test included friction force (Fx), normal load (Fz), coefficient of friction (COF), and mean square error (MSE).
- The polymer coupon samples were cleaned after each test and weighed on an electronic balance with a resolution of 0.1 mg. The weight of the retaining ring was measured before and after the test to record the change in weight / weight loss in milligram (mg) of the material.
- Mean Square Error (MSE) value was used to present the vibration properties of the material during the polishing process.

RESULTS AND DISCUSSION

A total of five polymer material compounds including PPS (polyphenylene sulfide), PC (polycarbonate), CFR (carbon fiber reinforced) Arlon, Arlon 1330, and Arlon EX-2618 were tested using a polishing Micro-Tribometer for coefficient of friction, mean square error, and weight loss.

The following Figures 2 to 6 show the friction coefficient data that was taken from the UMT Series

Micro-Tribometer Viewer software. This is the raw data of the friction coefficient, presented here to show a comparison between the polymer materials' stability and uniform characteristics from the time to get a break in the interface of the polymer material to the end of the test duration of 1800 seconds. Figure 2 shows COF measurement of CFR Arlon between 0 seconds to 1800 seconds. Comparing the COF measurement of CFR Arlon with Figures 3 to 6 for Arlon 1330, Arlon EX-2618, PPS, and PC respectively. Figure 2 also shows the highest stability indicated by the low variation in the high and low peaks in the plot and lowest COF of 0.4 between 200 and 1800 sec. compared to the other materials including PPS, and PC.

The high stability from the initial break in period for the polymer material through the duration of the test, in this case 30 minutes, indicated by the results of Figure 2 CFR Arlon is an advantage for CMP applications. Since the effectiveness of the retaining ring is measured by absence of large-scale topography, tight flatness tolerance, global planarization correlated to the high stability and low non-uniformity result in Figure 2.

Figure 3 and Figure 4 Arlon 1330 and Arlon EX-2618 friction coefficient respectively show comparative stability and uniformity characteristics to each other with both polymer materials having different lubricant filler in each compound.

Arlon EX-2618 resulted in a lower COF of 0.45 compared to Arlon 1330 of 0.6 between 200 and 1800 seconds, with both materials resulting in lower COF variation and lower vibration instability compared to figures 5 and 6 PPS and PC friction coefficient average of 0.9 and 0.7 respectively.

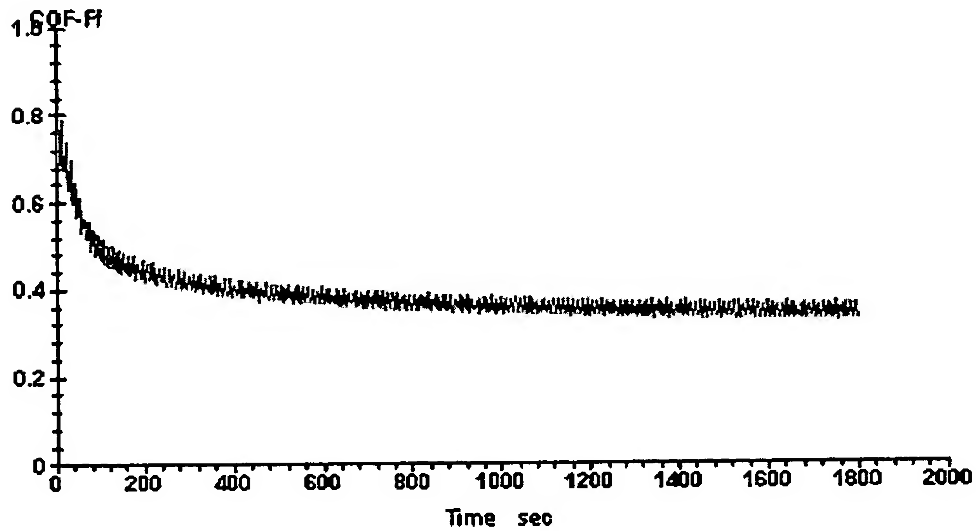

Figure 2: Friction Coefficient data taken from the UMT Series Micro-Tribometer for carbon fiber reinforced Arlon material.

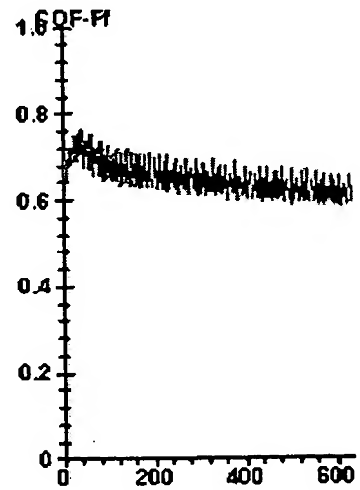

Figure 3: Friction Coeffi Tribom

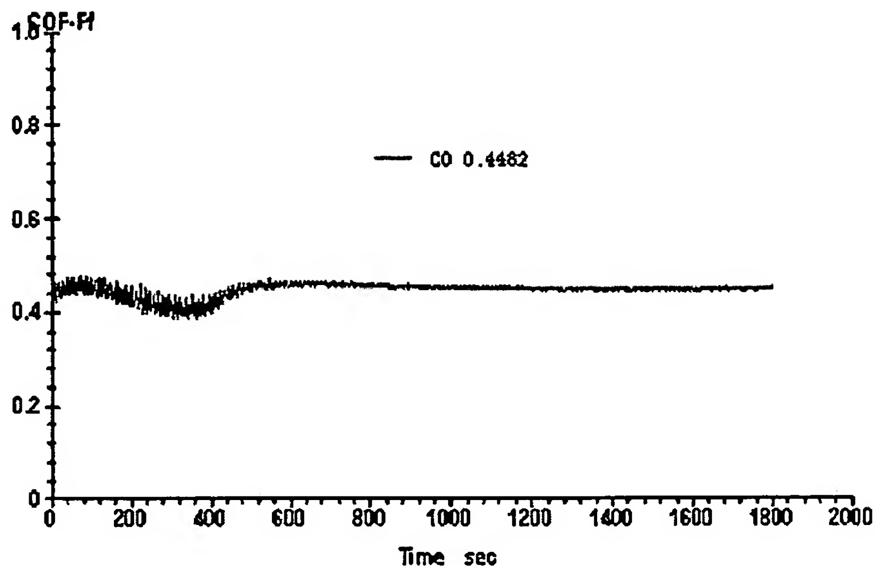

Figure 4: Friction Coefficient data taken from the UMT Series Micro-Tribometer for Arlon EX-2618 material.

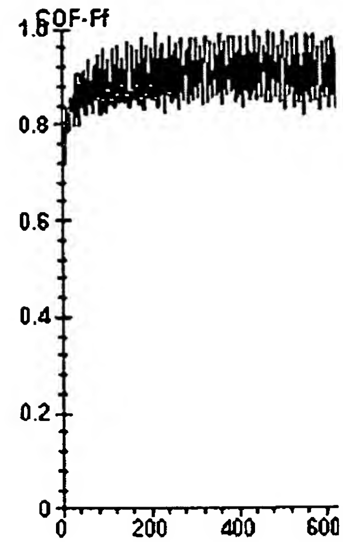

Figure 5: Friction Coeffi Trit

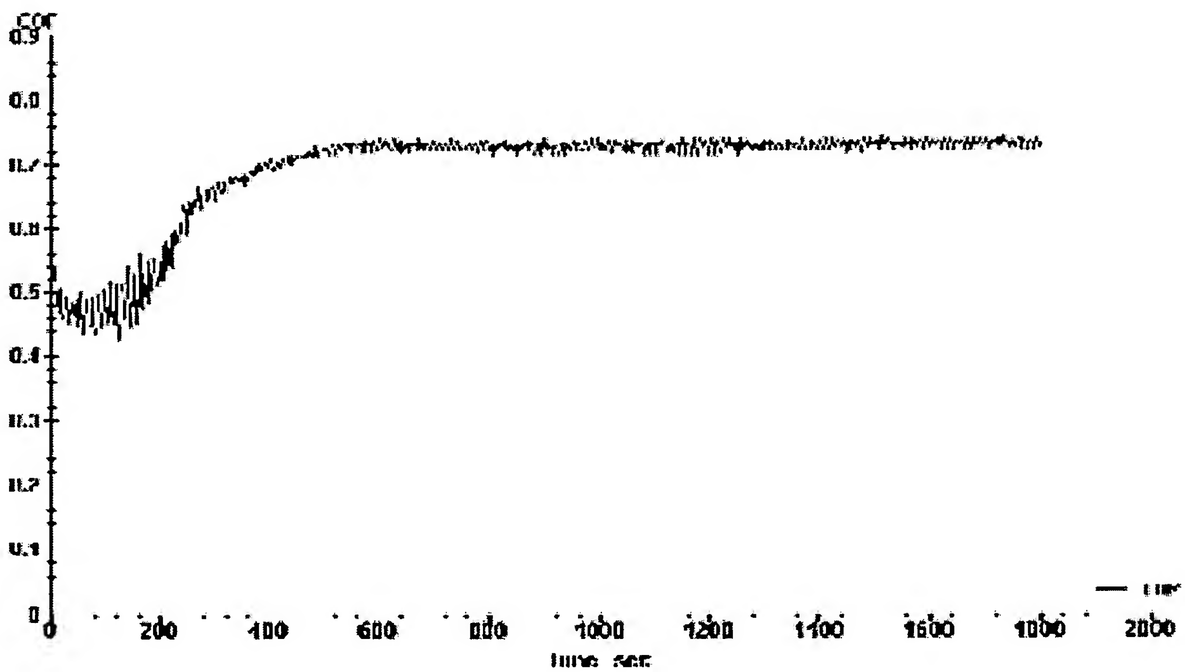

Figure 6: Friction Coefficient data taken from the UMT Series Micro-Tribometer for PC material.

Figure 7 is a comparison graph of the average COF for all the materials at 28-30 time interval with CFR Arlon resulting in COF of 0.4 that is more than 50% lower than PPS and 40% lower than PC under the same testing parameters. Figure 8 is a comparison of the Average Mean Square Error for all the included materials at 28-30 minutes duration.

Mean Square Error (MSE) is the standard deviation of the friction coefficient data from Figures 2 to 6.

While MSE is an indirect measure of the vibration resistance of the polymer material, it can be correlated to the vibration characteristic by the variation in the polymer materials' friction coefficient characteristic that is directly proportional to MSE. Therefore a small MSE value is optimal and will result in low vibration that is an important characteristic for achieving better polishing uniformity during the CMP process.

Arlon EX-2618 and PC displayed similar vibration resistance followed by CFR Arlon and Arlon 1330. PPS was observed to have had vibration that was more than ten (10) times higher than that of Arlon EX-2618.

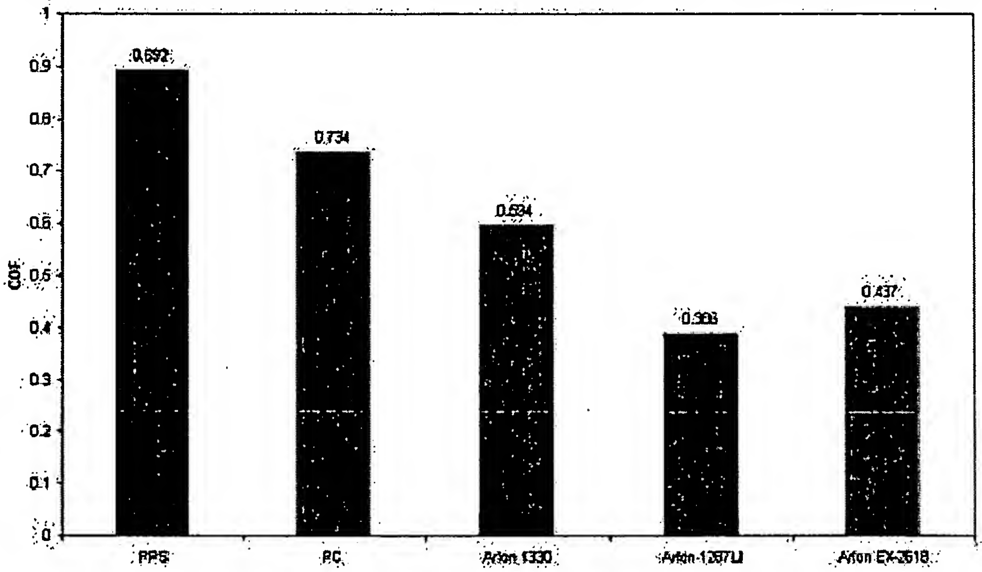

Figure 7: Average Coefficient of Friction comparison of all of the materials at end of test (28-30 minutes)

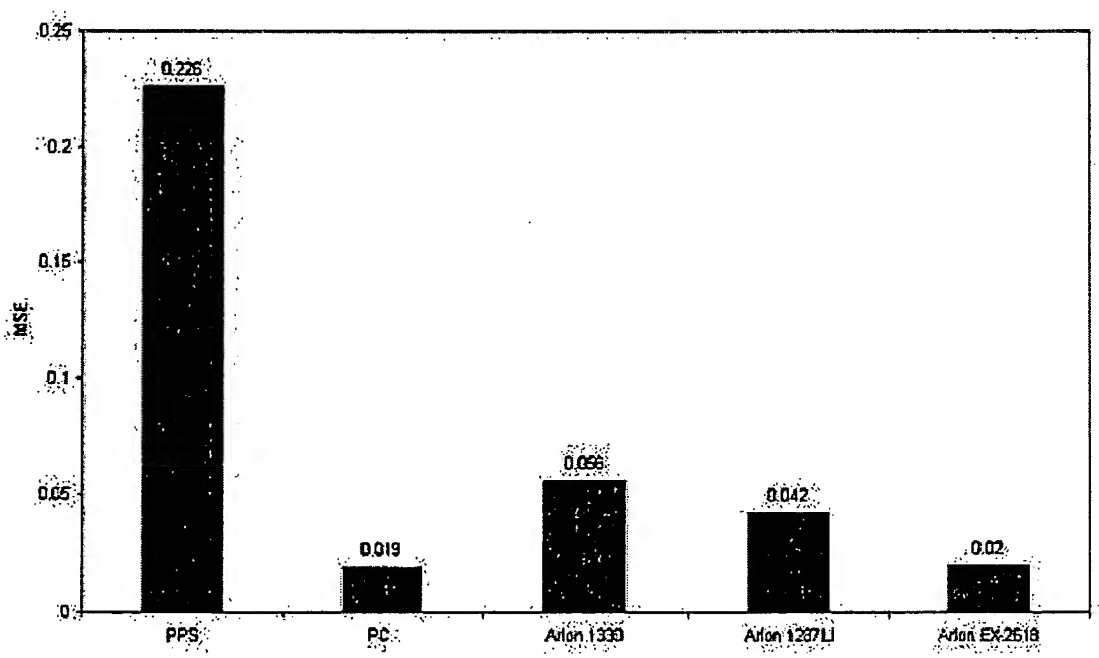

Figure 8: Average Mean Square Error comparison of all materials at end of test (28-30 minutes)

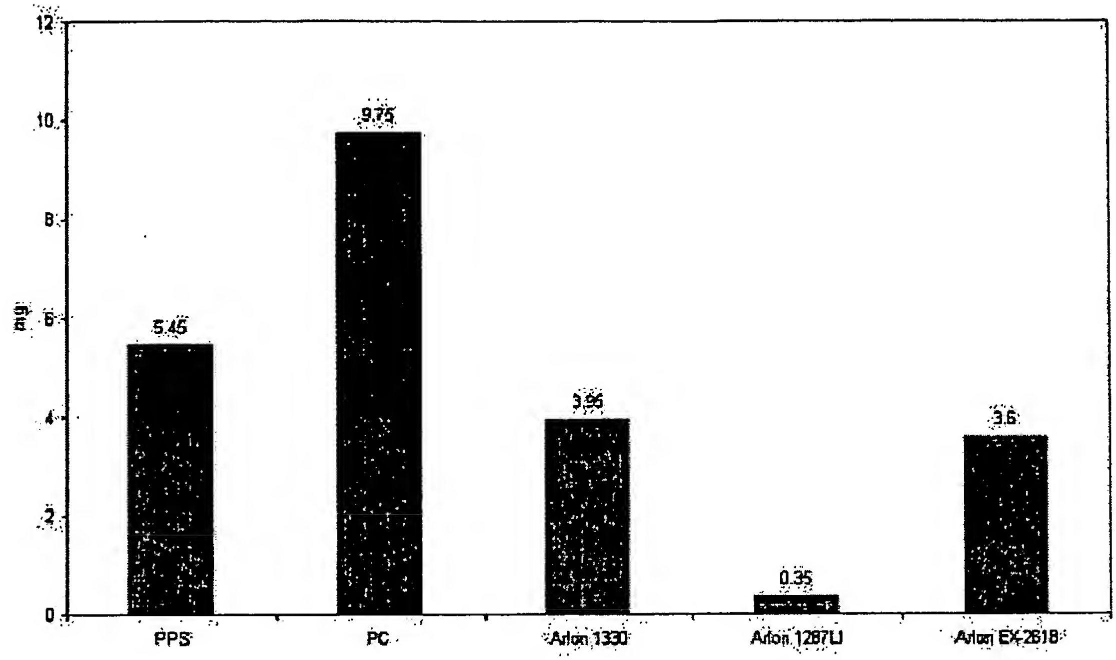

Figure 9: Average weight loss comparison of all referenced materials

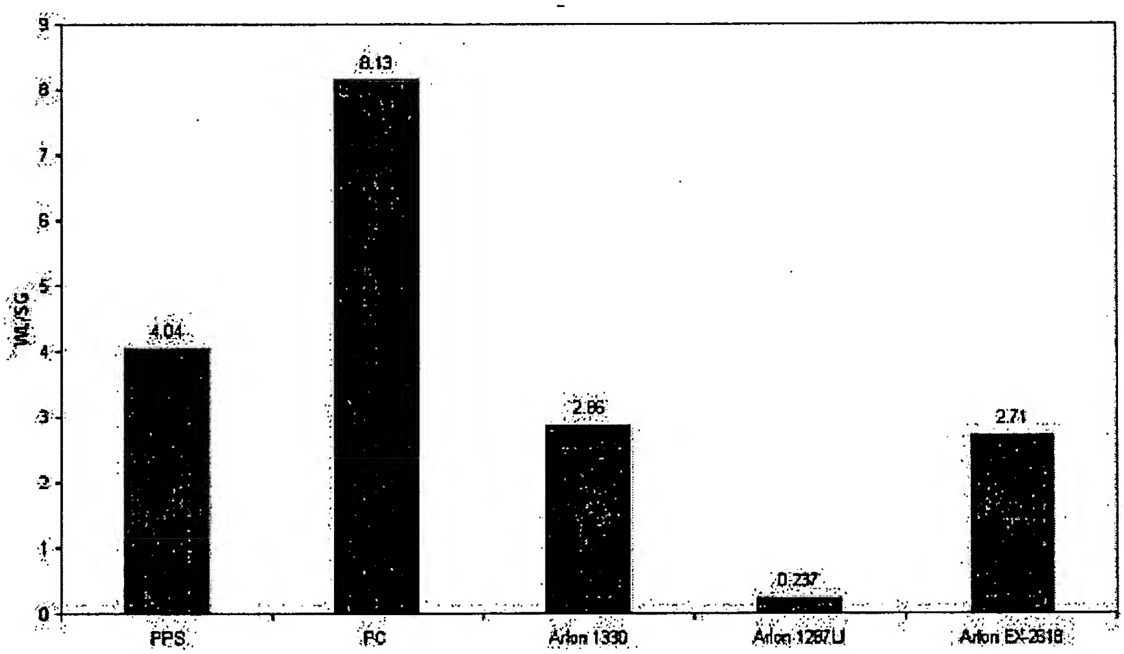

Figure 10: Wear factor comparison of all materials based on the average weight loss divided by the specific gravity

Figure 9 includes a comparison of the average weight loss in milligram for all the polymer materials under the specified testing conditions of 10 psi pressure and 5mm/sec oscillatory motion velocity. The samples were weighed before and after each test with a tolerance of 0.1 mg.

Polymer materials in critical tribological applications undergo both pressure and or a velocity induced failure. CMP application conditions are typically very low pressure/load and a continuous velocity motion that results in an increase in wear rate from a velocity induced failure. With this in mind an optimum polymer material for CMP applications would be one with a minimal weight loss.

CFR Arlon resulted in weight loss that is more than 90% lower than all the included materials. The low weight loss is an important characteristic for CMP applications where the polymer material retaining ring must be able to withstand the pressure velocity variable with a minimal generation of particles that can deposit on the wafer and affect the long service life.

Figure 10 is the calculated GTC wear factor based on the volumetric weight loss of the polymer material. GTC wear factor was calculated by dividing the weight loss of each material by the materials specific gravity.

In support of the above study, a large chip fabricator on the East Coast previously replaced their polycarbonate-encapsulated stainless steel retaining rings used in their metal and polysilicon processes after a service life of 3,000 to 5,000 wafers. Retaining rings based on a Greene, Tweed & Co.'s Arlon 1330 compound have consistently provided a service life of over 10,000 wafers for the same processes, a 2-3 X improvement in service life over the previous rings. This fab also reported that in their oxide process, the service life has exceeded the 10,000-wafer mark and the upper limit is still to be established.

CONCLUSION

Two (2) commonly used CMP retaining ring materials, PPS (polyphenylene sulfide) and PC (polycarbonate) and three (3) Arlon based CMP retaining ring materials from Greene, Tweed & Co., CFR Arlon, Arlon 1330, and Arlon EX-2618 were analyzed and tested for coefficient of friction, wear factor, and vibration. This was performed using Center for Tribology's (CETR) polishing Micro-Tribometer model PMT with consistent and repeatable results. Of these materials tested, carbon fiber reinforced (CFR) Arlon resulted in the best overall tribological performance with an exceptionally low wear factor, low friction coefficient, and excellent vibration resistance. In addition, Arlon 1330 and EX-2618 both outperformed PPS and PC in all the tribology parameters with consistent performance.

CMP retaining rings made from a variety of materials and compounds will continue to be required to satisfy the increasing demands for uniformity and planarity of film thickness with a decreased material removal rate. Along with this comes the demand for longer service life of critical components such as the retaining rings. Fortunately, next-generation CMP retaining rings made from high-performance thermoplastic compounds such as Arlon PEEK are available for tomorrow's demanding systems today.

Future Developments

As microchip features shrink to the nanometer scale, the efficiency of the CMP process is vital to achieve the sub-micron features. CMP retaining ring efficiency is determined by uniform and low removal rates for tight process control and long service life. Future developments are under way for next generation CMP retaining rings with innovative polymer materials and new design concepts to achieve the high yields and productivity required for smaller device manufacturing.

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